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TEXAS TECH UNIVERSITY

Temperature Knowledge and Model Correlation for the Soil Moisture Active and Passive (SMAP) Reflector Mesh

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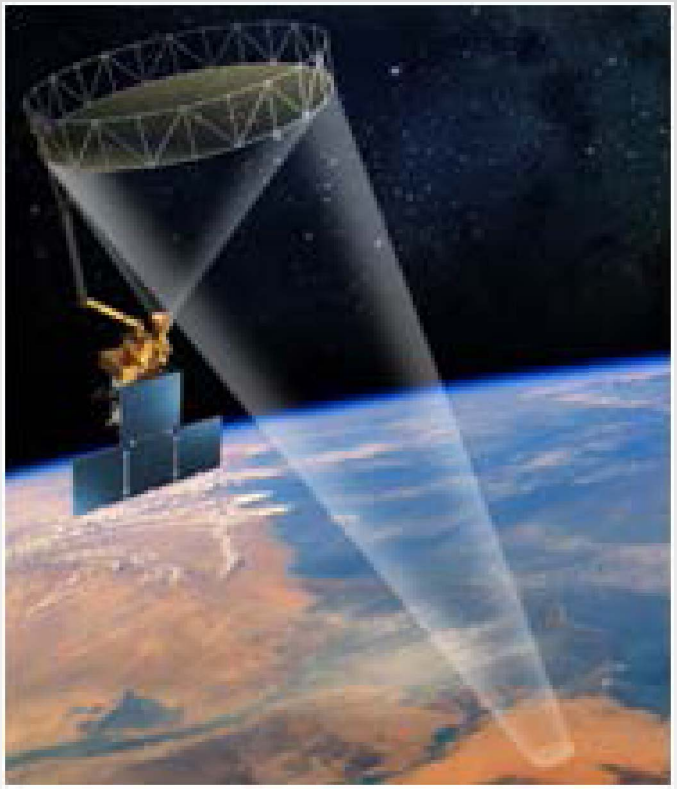
SMAP Mission Objectives



http://smap.jpl.nasa.gov/

- Direct observations of soil moisture and freeze/thaw states from space

- Improved estimates of water, energy and carbon transfers between land and atmosphere

- Enhanced weather and climate forecasts, improved flood prediction and drought monitoring

SMAP Team Members and Responsibilities

- Radiometer and ground science data processing (GSFC)

- Radar, instrument integration, test and prelaunch mission management (JPL)

- Reflector boom assembly (Northrop Grumman)

- Spin mechanism assembly (Boeing)

SMAP and Aquarius/SAC-D

Both fly a GSFC radiometer and JPL radar but:

SMAP

- Measures soil moisture and freeze/thaw states

- Single feed horn exposed to the sun

- Spinning platform

- 6m deployable spinning antenna

- 0.7°C/orbit thermal stability requirement

Aquarius/SAC-D

- Measures sea surface salinity

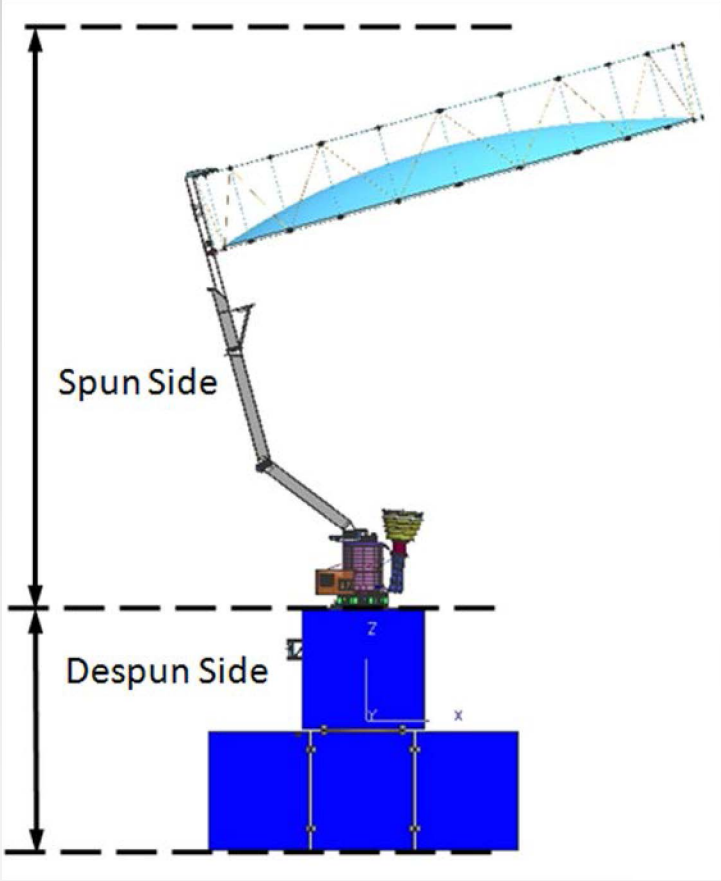
- 3 feed horns permanently shadowed

- Non-spinning platform

- 2.5m fixed antenna

- 0.1°C/week thermal stability requirement

Instrument Configuration



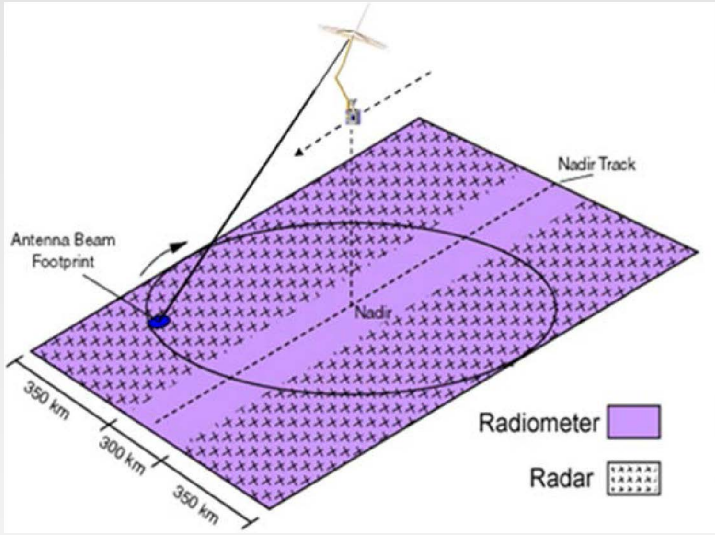
- The L-band radar components are on the despun side of SMAP

- The L-band radiometer resides on the spun side of the observatory
  - - Cylindrical core structure (CS) houses Spin Mechanism Assembly (SMA)
  - - 4 major assemblies mounted on CS
    - - Reflector Boom Assembly (RBA)
    - - Integrated Feed Assembly (IFA)
    - - Radiometer Back End Assembly (RBEA)
      - Instrument Control Electronics(ICE)

Derivation of Thermal Stability Requirements

Soil moisture error budget → **Antenna temperature calibration** → **Feed to Electronics input and RF loss and emission** → **Brightness temperature**

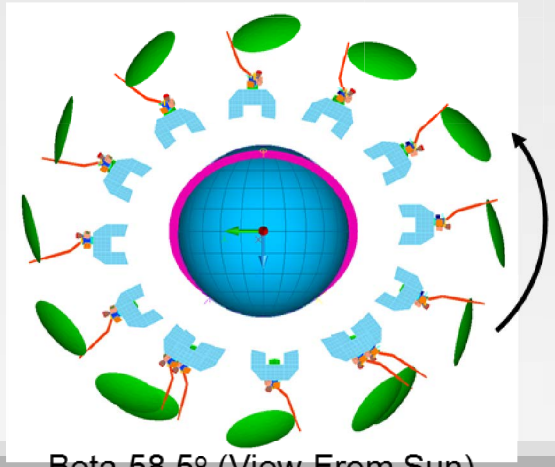
- An acceptable error was allocated to four time periods
  - Instantaneous per minute rate
  - Change per orbit, month and mission life
- Mesh temperature knowledge is an allocated item in the radiometric error budget
  - Temperature knowledge within 60°C required



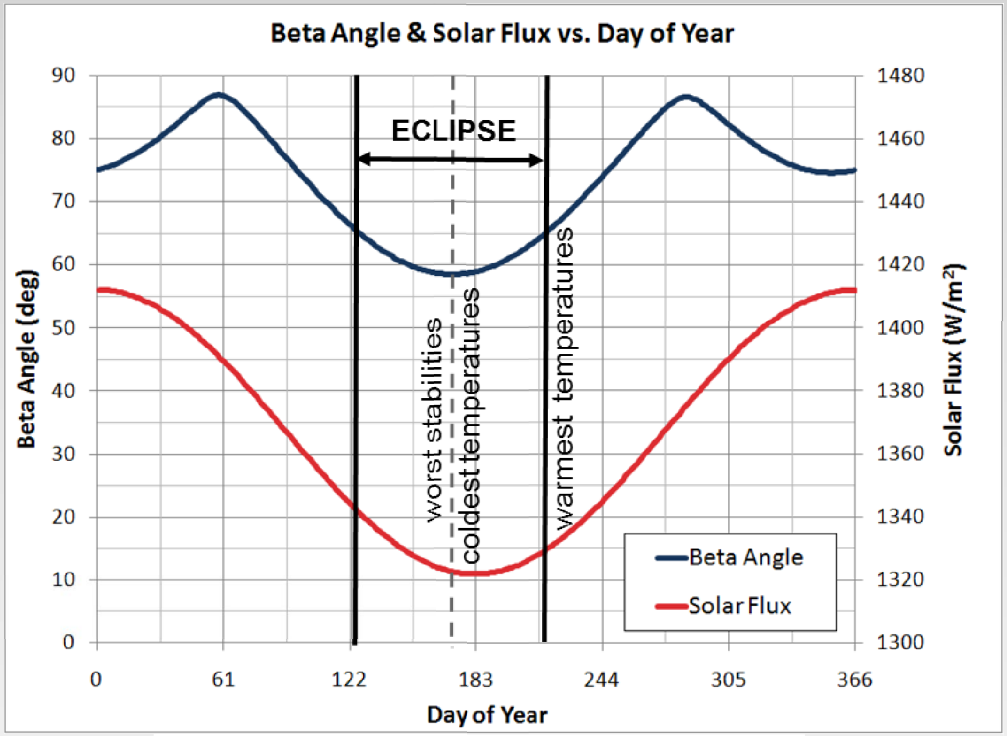
Thermal Environments

SMAP orbital parameters

- sun-synchronous 6PM AN orbit
- 685 km altitude
- orbital period is 98.5 minutes
- beta angles range from 58° to 88°
- eclipse when 58° ≤β≤ 65°
- max. eclipse time = 18.9 minutes
- no eclipse when 65° ≤β≤ 88°
- eclipse event lasts approximately 83 days from May 11 to August 2



Beta 58.5° (View From Sun)



Environmental Parameter	Hot Case	Cold Case
Solar Constant	1420W/m²	1290W/m²
Earth IR	250W/m²	190W/m²*
Albedo Factor	0.35	0.25

* Recommended by Aquarius Thermal Team

Approach and Test Objectives

- Mesh temperature knowledge to within 60°C is critical to the radiometric performance
  - It's a requirement and an allocated item in the instrument error budget

- On-orbit mesh temperature will be predicted using a correlated analytical thermal model
  - No direct measurements from in-situ flight thermal sensors due to the small wire thickness

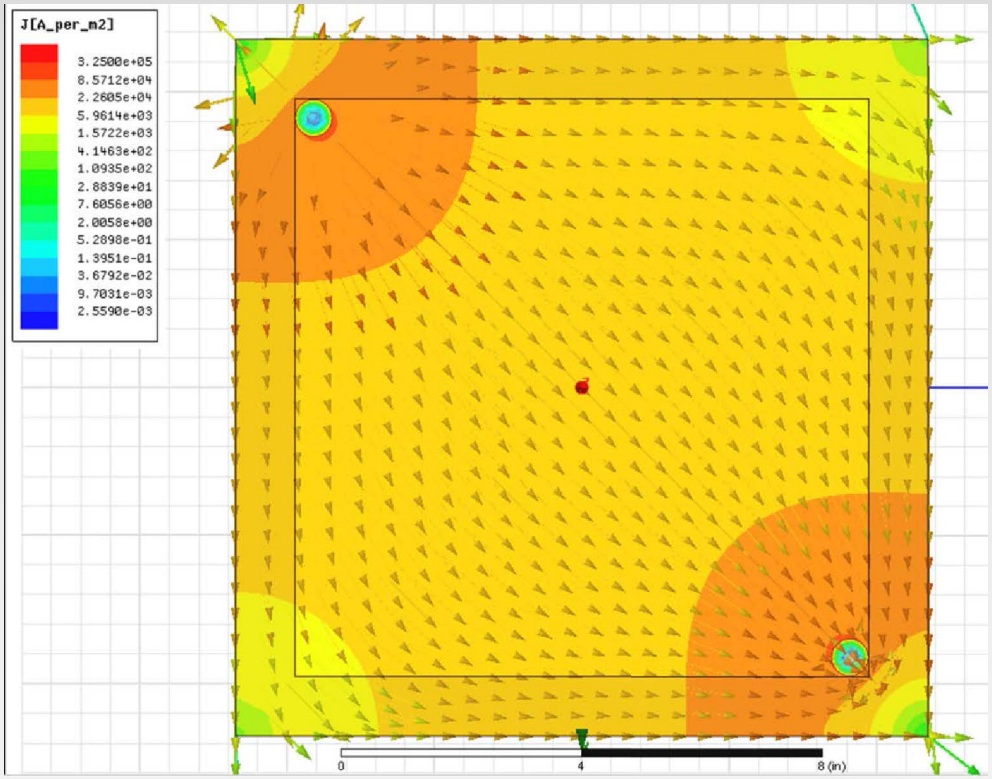
- The primary test objective was to use results from the mesh temperature knowledge test to verify requirement compliance
  - Measured electrical resistances of mesh test article under flight-expected conditions to estimate the mesh temperature (used data from earlier in-air calibration test in an oven)
    - Flight-like mesh (material, thickness, tension) under solar illumination at various incident angles
  - The mesh temperature measurements from the test then were used to correlate to a simple thermal model of two representations of the mesh (plate and torus) to verify if the temperature was predictable to within 60°C.
  - The best-fit representation of the mesh thermal model will then be substituted for the mesh in the SMAP instrument-level thermal model.

Test Article

- Mesh
  - - sample from flight mesh: 1.2 mil gold plated molybdenum with 20 openings per inch)
  - - flight-like tension
- Frame
  - - 9.75” x 9.75”
  - - 0.25 inch wide
- Clamp
  - - made of copper
  - - 1.325” from the frame corner

Model for Current Flow through Mesh

- Using both Matlab and Ansys Maxwell 3-D current models were used to evaluate effects of frame width and clamp location
  - - estimate current amount through mesh under frame with various locations of clamp
  - - Current flow through 1” frame with copper clamp at the corner of frame is shown

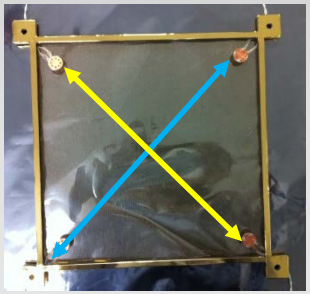


Effects of Frame Width & Clamp Position

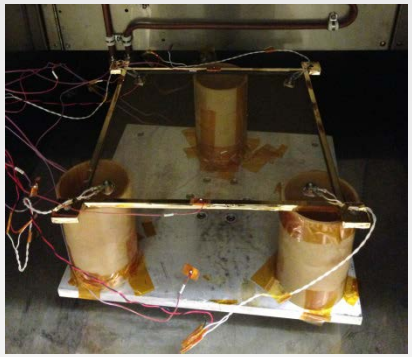
Clamp Location	1" Frame		0.25" Frame	
Distance from Corner, inches	% Current thru Mesh	Simulated Resistance, ohms	% Current thru Mesh	Simulated Resistance, ohms
0.7	--	--	89.8	1.79E-01
1.3	72.2	1.41E-01	92.0	--
2.0	77.6	1.13E-01	--	--
2.5	80.6	1.00E-01	--	--
3.0	83.0	8.87E-02	94.9	8.87E-02
3.5	85.1	7.76E-02	--	--
4.0	87.0	6.81E-02	--	--
4.5	88.8	5.77E-02	--	--
5.0	90.7	4.53E-02	--	--

Mesh Calibration (Resistance vs Temp)

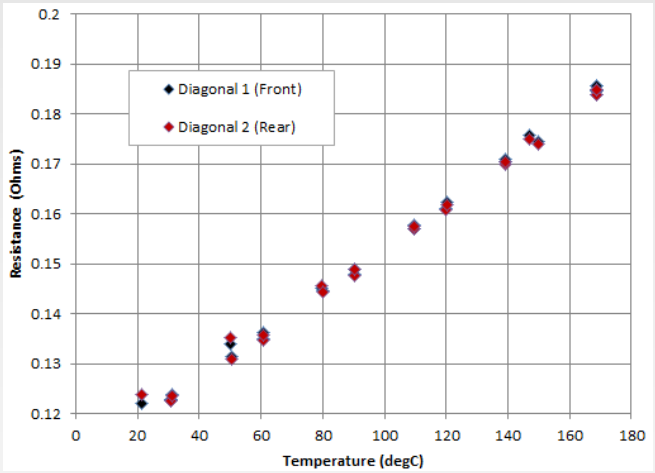
2'x2'x2' Environmental Chamber



Measured along both diagonals



Test Setup



R vs T

Test Facility

- 3’ vacuum chamber
  - 17.75” quartz window
  - shroud temperature controlled by GN_2
- Solar simulator
  - Spectrolab X-25
  - 2.5 Sol at 1AU
  - 9”x9” @ quartz window

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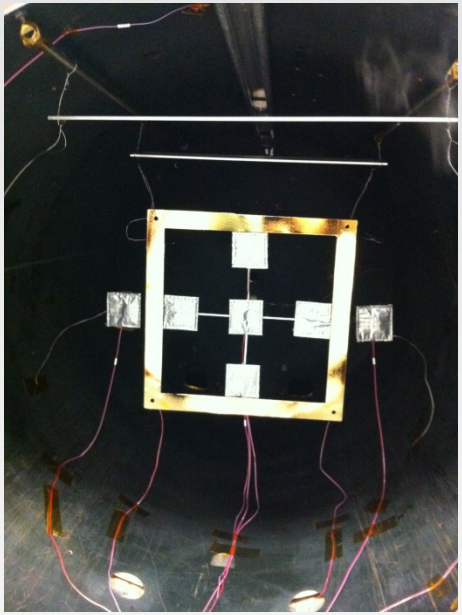
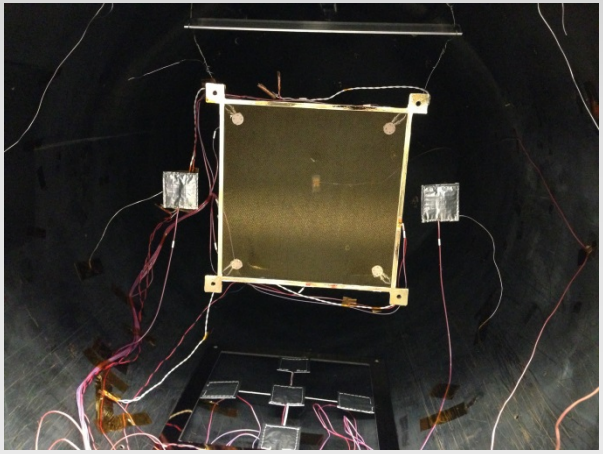
Solar Beam Survey

- calorimeter
  - Front face: germanium kapton
  - thermocouple attached at the back of front sheet
  - MLI at the back
- Locations of calorimeter
  - 5 inside of test article
  - 2 out side of test article: used for monitoring of the beam strength during entire test
- Beam survey @ 3 locations
  - 18”, 22” and 26” from the quartz window

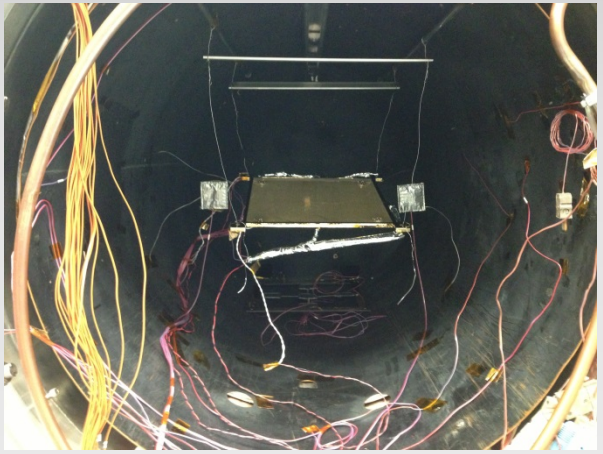
Calorimeter
(germanium kapton)



Test Setup and Test Conditions



Setup at 90°



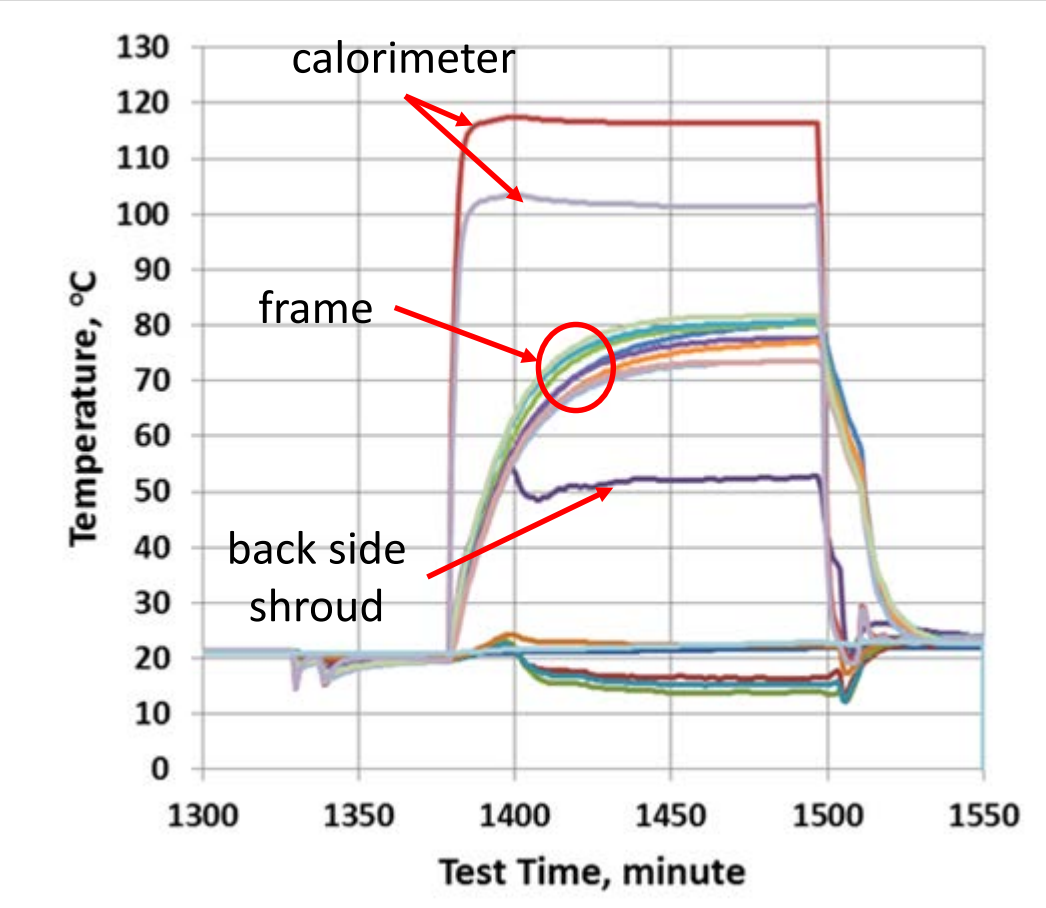
Setup at 15°

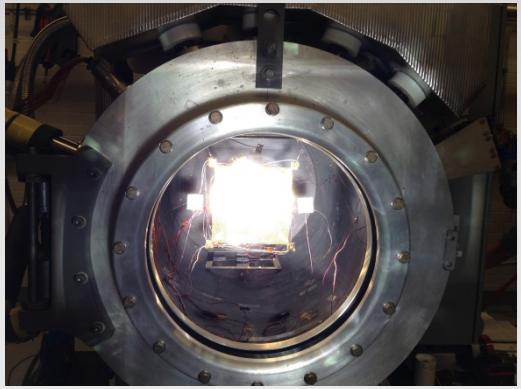
- Test article hang by stainless wires at 22” from the quartz window
  - - two reference calorimeters used to monitor beam strength

- Five incident angles: 90°, 45°, 30°, 15° and 10°
  - - Shadowing effects of the frame on the mesh becomes dominant for angles less than 10°

- Averaged beam intensity of 1447W/m^2 at 22” from the quartz window used for the entire test

Test Results with Attack Angle of 90°





- Mesh resistance
  - - diagonal 1: 0.502 Ω
  - - diagonal 2: 0.497 Ω

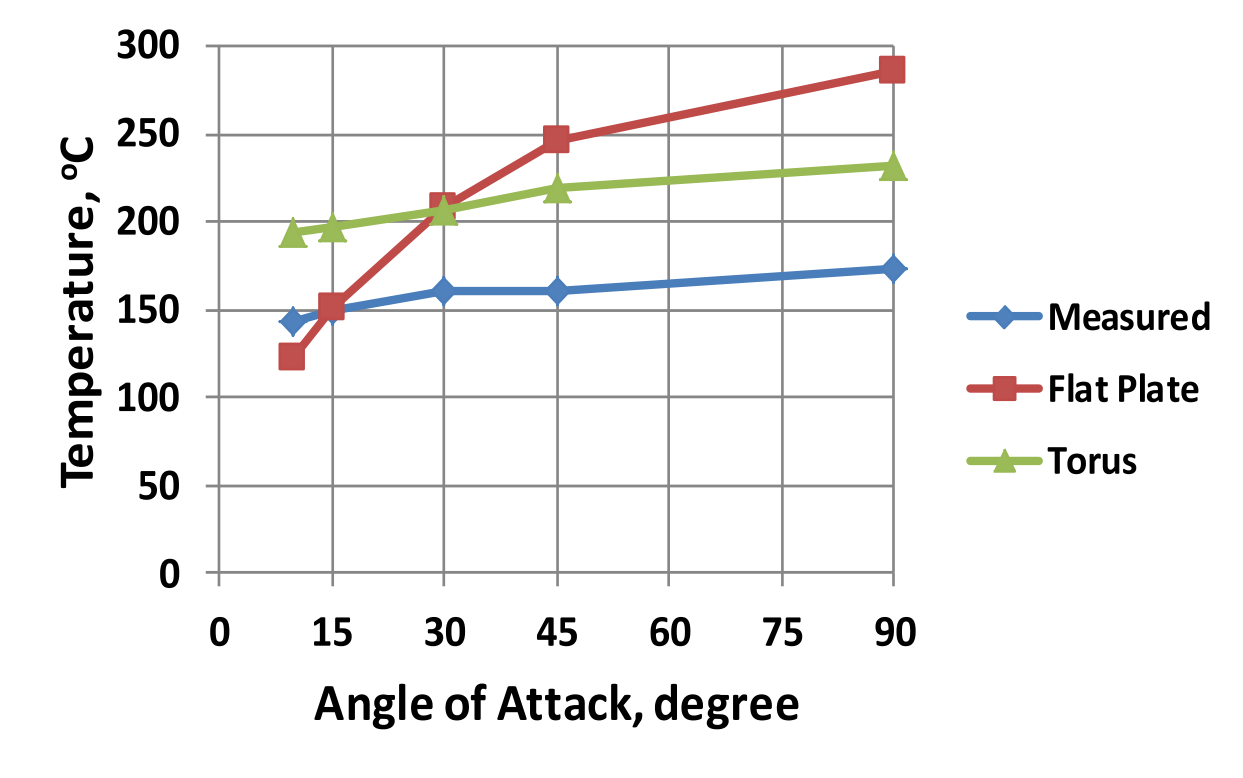
- Back side shroud was warm due to beam illumination even though it was flooded with GN_2

Test Results with Various Angle of Attack

Angle of Attack [°]	Resistance (Ω)			Temperature (°C)			T^*_{avg} (°C)
	dia1	dia2	avg	dia1	dia2	avg	
90	0.502	0.497	0.500	160.7	159.3	160.0	173
45	0.463	0.461	0.462	150.1	149.5	149.8	160
30	0.482	0.476	0.479	152.2	150.6	151.4	161
15	0.420	0.417	0.419	137.3	136.5	136.9	149
10	0.399	0.391	0.395	129.8	127.7	128.8	143
* Includes Frame Temperature Correction							

- Two diagonal measurements are very close to each other

Test Results with Model Predictions



- Torus model shows good agreement in slope with test data but they are about 50°C lower than measured values

Torus Model Correlation with Various α/ε

T_{avg} (°C)	$\alpha/\varepsilon = 7$		$\alpha/\varepsilon = 5$		$\alpha/\varepsilon = 4$	
Measured, °C	Torus, °C	ΔT, °C	Torus, °C	ΔT, °C	Torus, °C	ΔT, °C
173.0	232.1	59	199.7	27	176.9	4
160.0	218.6	59	186.3	26	165.6	6
161.0	207.0	46	176.1	15	157.7	-3
149.0	197.7	49	167.3	18	147.9	-1
143.0	194.4	51	164.3	21	146.0	3

- With α/ε = 4, a simple torus model correlates the test data within $\pm$ 10°C which meets the temperature knowledge requirement of 60°C with margins.

Summary

- An electrical resistance measurement can be a good indirect method to measure temperature of a thin wire mesh.

- The woven mesh used in the SMAP reflector can be modeled using simple torus geometry.

- The measured mesh temperatures were well correlated (within 10°C) by a simple torus model with optical property ratio of $\alpha/\varepsilon = 4$ which can meet the knowledge requirement of 60°C with margins
  - - Original assumption for α/ε was 7